The Use of Spot Markets for Water Allocation

Mark Milke, Department of Civil Engineering, University of Canterbury, Private Bag 4800, Christchurch, New Zealand.

John Raffensperger, Department of Management, University of Canterbury, Private Bag 4800, Christchurch, New Zealand.

ABSTRACT

Research is underway throughout the world into alternative approaches to water allocation that can maximise economic efficiency while respecting environmental bottom lines and ensuring the rule of law. One innovative programme, led by researchers at the University of Canterbury, is examining the potential for a spot market for water. Building on the successful implementation of a spot market for electricity in New Zealand, the approach would accept bids for the purchase or sale of water, and then find the water allocations that optimise the economic benefit to society.

The approach uses a number of constraints on optimisation reflecting the physical limits to water availability, and also reflecting environmental objectives. The latter can include a minimum stream flow constraint and a maximum drawdown constraint to limit seawater intrusion. Unlike other water trading approaches, this approach does not require negotiating and evaluating a series of transfers between pairs of users; instead, the approach can consider all water users and their unique needs simultaneously, while ensuring environmental compatibility. The research is advancing along three lines: (1) investigation of the level of model sensitivity and its effects on the operation of the market, (2) study of the potential methods of operation of the model (e.g., 'user-pays', 'user-trades', user co-operative), and (3) consultation with interest groups to identify practical concerns.

THE NEW ZEALAND SETTING

Water allocation in New Zealand has moved to the front pages of newspapers, and has become an issue of national significance. In more and more of the country, water is judged to be 'fully allocated' or will soon be judged so. Some users need more water, while other users have not used all their consent. The current consent system is expensive to operate, is perceived by users and the community as being a risky way to ensure supply or environmental protection, and is slow to adapt to new supply data or changes in user demand.

The Water Programme of Action (WPoA) was established in 2003 as a joint effort of the Ministries for the Environment and Agriculture and Forestry to examine freshwater management in recognition of the urgency for action by the country as a whole to what had been perceived as unrelated local issues. The WPoA has recommended a set of actions (MfE, 2004) including:

• Collaboration between central and local government, scientists and stakeholders regional councils and scientists on pilot projects to demonstrate and test new water management initiatives (Action 13).
• Enhancement of transfer of allocated water between users (Actions 7 and 11).

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In general terms, central government in New Zealand recognizes that better market systems are needed to enhance the transferability of water permits, and offer financial incentives for improving the efficiency of water use. On the other hand, trials or research into water market systems has been very limited.

THE GLOBAL SETTING

The world is faced with a water crisis as demand grows without an increase in supply. The type of water crisis we face is open to debate:

> 'There is a perception of water shortage, especially during drought periods. But this perception is largely the result of existing institutions for water management, institutions that were designed in an era of abundance. One matter is clear – water users respond to incentives, and when water becomes more expensive, they conserve and use it more efficiently without much effect on overall welfare. I argue, therefore, that we do not have so much a water scarcity crisis as we do a water management crisis.' – David Zilberman (1994)

Our research is into better water management processes, and follows from the recognition that the price paid by water users almost everywhere in the world is less than the true marginal cost to society of additional water use, and hence is underpriced. Some pricing mechanism is desperately needed (Dinar & Subramanian 1997). True marginal cost prices maximize what is called the 'consumer surplus,' which is the sum of the differences, over all consumers, between each user's value and the price they pay. Marginal cost prices would signal users where and when to use water, where to install augmentation (e.g., dams), and how much to pay for it. Political pressure to fund new dams or restrict new water use would be easier to resolve if accurate signals, in the form of the prices of water, were available to all.

Price signals can also make environmental protection more effective. Current allocation systems are prone to criticism from those who want more and less water use. Those who want more water use believe that environmental protection is too tight in too many places, and that little regard is made for the economic impact of increased environmental protection. Those who want less water use believe that approval for water use is allowed because of economic benefits to a select few without full study of the potential environmental impact. The result of this impasse is not investigation of the optimum system that best meets both economic and environmental needs, but instead is a political 'winner-take-all' approach by both sides. The introduction of prices into the current stand-off would allow for discussion of the relative benefits and costs of increased or decreased water use in various places within a catchment. An allocation system that provides price signals while also reducing power struggles over water is desperately needed.

Economists and international leaders have stated for years that fresh water should be managed through markets, with the caveat that such markets must be designed correctly. However, no one has described how to set up a water market that accounts for users' effects on each other and on the environment. Many previous market approaches have not been able to have the price reflect the true marginal cost of additional water use. Water trading experiments (such as in Chile and parts of Australia) have received criticism due to errors of market design.

The hydrology makes trading complicated because each user affects every other user. Matching buy and sell orders cannot be done pair-wise, because any pair-wise trade would affect other users and the environment. Instead of a trading system, our research focuses on a spot market system where a user buys from (or sells to) everyone else at once. To find the best allocations in a spot market, the market manager requires a computer system with a hydrology simulation and an optimization procedure.

Most water use is by relatively large and sophisticated concerns (e.g., agricultural businesses, electricity generators, local government). Much of the contention in water allocation is between these large users. By relieving the constraints of fixed allocations between large users, acrimonious legal debate can give way to flexible market activity. Any successful market system must allow for new high-value uses of water to replace existing low-value uses, while compensating the existing users.

METHODOLOGY

The system under development has three parts: (1) an interface for users' bids, (2) a hydrological response model, (3) constraints on water use, and (3) and an optimization model to determine prices and allocate water.

Interface for users' bids

Users would be expected to give their marginal demand/price curves in the forms of a series of reserve values for water. Users would give a high value for the first amount of water they receive and lower values for additional water. An example of a user bid page is shown in Figure 1. In the example, the user (Well01) has had their allocation reduced from 1 unit of water to 0.17 units of water because of a severe drought. The user has decided to try to buy 0.3 units of water if it can be bought for $2/unit or less, to buy an additional 0.3 units of water if the price is $1.5/unit or less, and to buy a further 0.3 if the price is $1.0/unit. On the other hand, the user also understands that water could be very valuable and it might have a higher value to other users and so is willing to sell 0.08 of the 0.17 units of water available if the price is $2.5/unit or more, and willing to sell a further 0.08 (leaving only 0.01) for $3/unit. If the market value of water at this user's well turns out to be between $2 and $2.5, the user would neither buy nor sell water. Notice that the user is not compelled to buy or sell. Furthermore, the user might pay less than the offered buy price, or may sell at higher than the minimum sell price.

To bid sensibly, users will need some idea of what the market price for water will be, and tentative auctions can be held to assess likely value. Users would also want to have access to information on past bidding rounds and even meteorological forecasts.

Improvements in internet commerce and the familiarity of many people with internet bidding systems (e.g., TradeMe), implies that an online market for water is more feasible than it would have been years ago, when traders would have needed to be present in the same room for an auction.

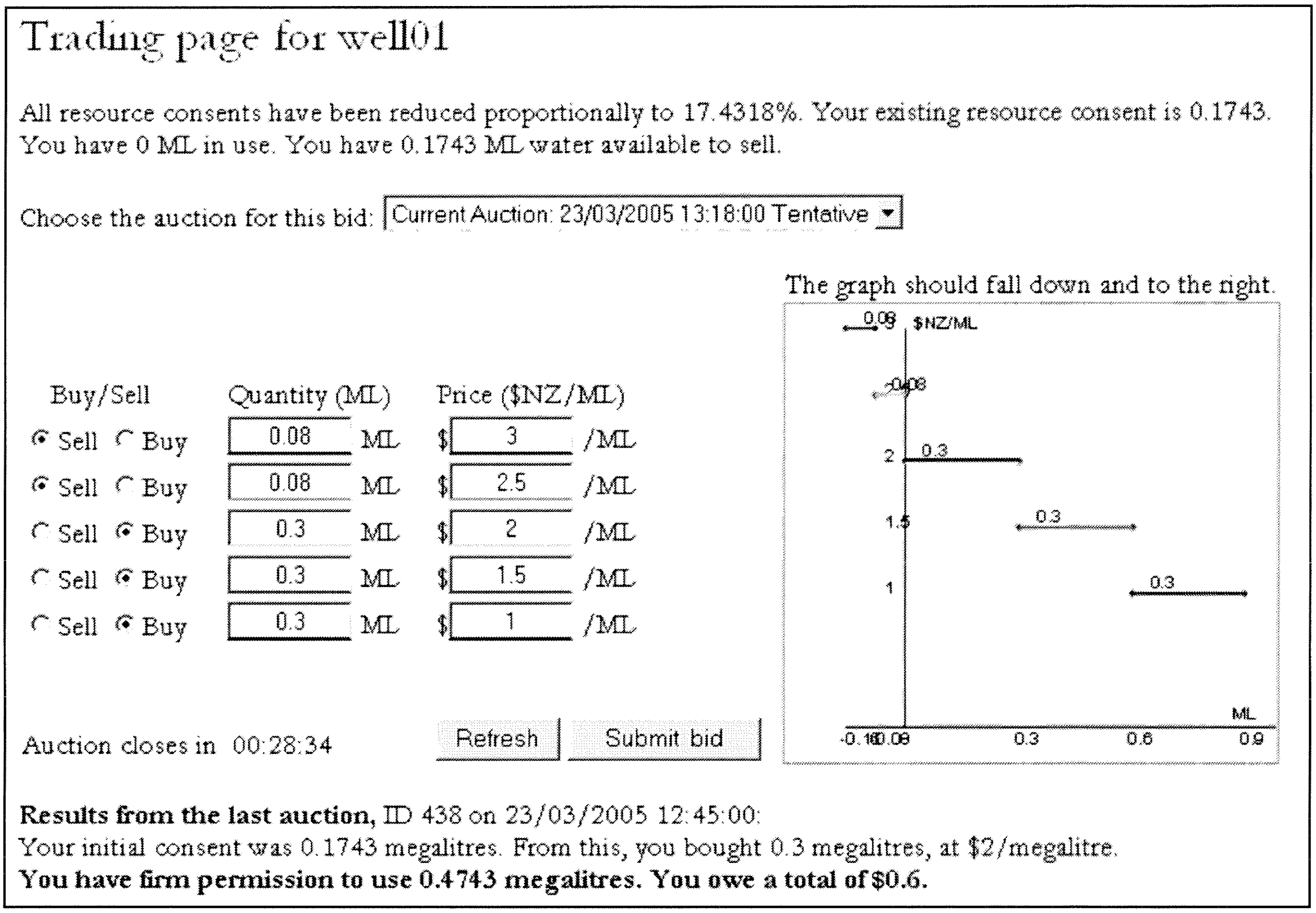

Figure 1: Sample user bid page

Hydrological response model

In the proposed water trading system, there exists capacity limits on the amount of water that can be delivered to a user or that can be made available for sale. In other words, some users are more hydrologically connected than others, and additional water use in one part of the system can have a different effect on each user elsewhere in the system. To assess the optimum water use, we need to know the marginal effect of each abstraction on every other user. These marginal effects can be found for groundwater users using the program MODMAN (Greenwald, 1998). MODMAN takes a standard MODFLOW model of a catchment and finds the effect of a unit of water use on the water availability (as measured by head) for every other user. This information is provided as a response matrix.

This response matrix approach was developed to find out how much water should be pumped from each of a series of wells being used to control the migration of groundwater contaminants; it works by varying the flow in each well to optimise (minimise in this case) the total amount of pumping. By the principle of superposition, overall impact at one well can be estimated as the sum of the effects of pumping from the other wells. When the assumption of superposition appears unreasonable, a new response matrix can be developed to represent the changing circumstances. For a water market, the software is modified to vary the flow in each well to optimise (maximise in this case) the consumer surplus. When the assumption of superposition appears unreasonable, a new response matrix can be developed to represent the changing circumstances.

Constraints on water use
The optimization of consumer surplus requires the careful input of proper constraints on water use. Examples are water pressure difference constraints to ensure water flow into streams, water elevation minima to ensure no long-term exploitation of the resource, and water elevation minima to limit sea water intrusion, or catchment-wide maximum water use to meet sustainable water yield goals. Physical constraints might also be required, such as the total flow capacity of an irrigation canal.

The values chosen for the constraints are the result of social consultation and are typically found in catchment management plans. They have often already been translated into an appropriate form for a computer model to allow water resource planners to evaluate the potential effect of water allocations. Rather than being used only for occasional assessments of the water that can be allocated in a catchment, these constraints are used operationally in the market system every time an auction is held. In this way, the market system would provide at least as good environmental protection as is currently available.

Optimisation model to determine prices and allocate water
The optimization uses a common technique of operations research known as linear programming. The variables are the water flows for each user, the constraints are as described above, the user inputs are the bids, and the model optimizes consumer surplus. The result of the optimization is not only the water flow for each user, but also the marginal value of additional water at every location of interest. The price can be found even at places where there is no water user, say at a river. The price at a given location is calculated as the cost to everyone else if that user were to take one more unit of water, which is the marginal cost. Users are then charged (or paid) for their purchase (or sale) at their local price.

The size of the linear program depends on the number of wells required, the number of environmental control points, and the number of time periods. The linear program can be solved easily in a few seconds with open source software. Even for complex real-world hydrological systems, the linear program would be of a modest size by typical operations research standards.

SAMPLE RESULTS

Two sets of sample results are presented: one with hypothetical hydrogeology and another with realistic features. The first one is for a small catchment that only receives water from rainfall, and only has 18 water users, all with 1 unit of water allocation under normal conditions. The catchment is shown in plan view in Figure 2. A drought means that all water users have had their allocation reduced to 0.17 units of water. All users are assumed to have the same demand/price curve with users willing to sell down to 0.05 units of water only if the price is $4 or more, while users are willing to buy water to reach 0.4 units if the price is $3 or less, and willing to buy water to reach their pre-drought allocation of 1.0 units if the price is $2 or less, and willing to buy excess water if available to 6.0 units if the prices is $1 or less. The results are shown in Figure 2.

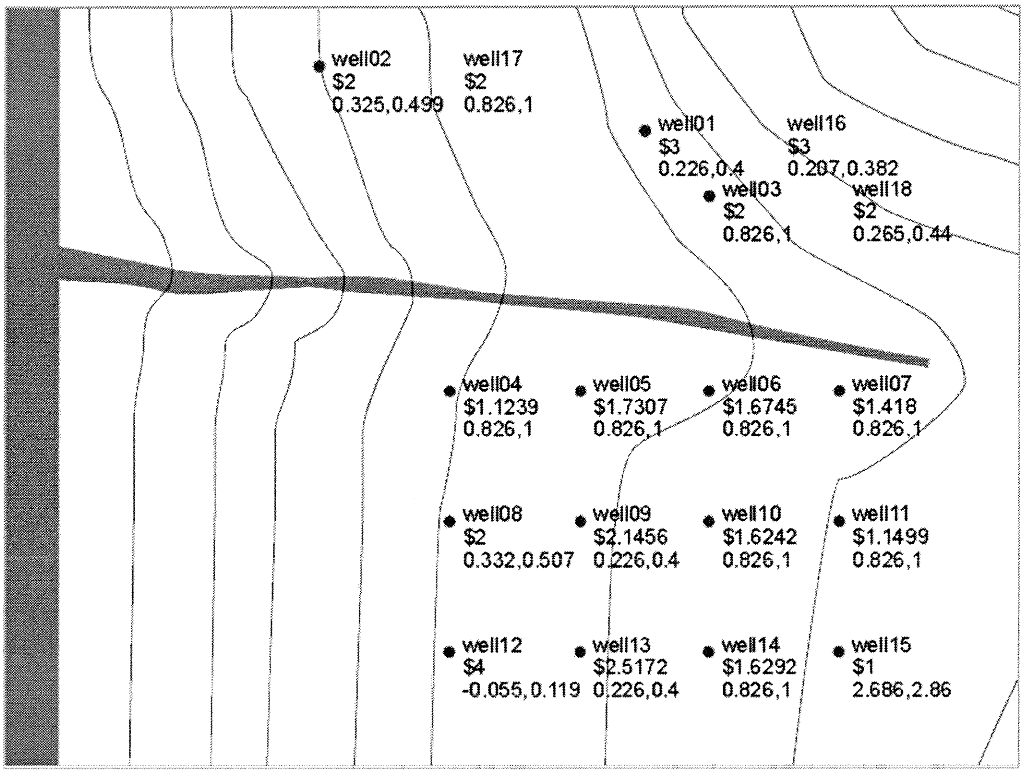

Figure 2: Price map for hypothetical scenario where all initial allocations are reduced from 1 to 0.17 units, and then users are allowed to buy and sell. At the left is the sea, a stream runs through the middle of the area, the other boundaries do not allow flow, and the black lines are the contour lines for water pressure prior to the auction. The numbers shown are: user name, local water price per unit, purchase (+) or sale (–) of water units, and total allocation of water units after purchase/sale.

Notice first that trades do occur even though all users have the same value for water. This is because the environmental constraints on water mean that water is more expensive near environmentally sensitive locations, and users close to locations where the constraint is more severe pay more. For example, in Figure 2, the value of water for Well 12 is $4, while the value of water for Well 15 is only $1. This is because a seawater incursion constraint is active near Well 12 and Well 12 is not able to harvest much rainfall because of the nearness to the southern boundary of the catchment.

This may strike some as being inequitable, but consider that it sends a clear signal that only the most socially productive uses of water should be considered in locations where large environmental impacts are more likely, thereby shifting more consumptive water use to locations where water use would cause less harm (in this case, further away from the coast and the stream). In this example, the high price at Well12 has led this user to sell water. The willingness of Well 12 to sell has allowed the neighbours to use more water than they otherwise would in a drought, but required a monetary transfer from the neighbours to Well 12 as compensation. All users have traded, all users have benefited from trading, and the environmental bottom lines have been respected.

The first example is simplified because it does not consider a suitably complex hydrogeology or the many more users existing in real world catchments. The second example considers the Wairau River catchment and the city of Blenheim in the Marlborough District of the South Island of New Zealand.

The catchment is 21 by 26 km and there is an existing MODFLOW representation for the groundwater in the catchment, including a sophisticated connection between surface and groundwater. Environmental constraints have already been identified and expressed in model terms. For this study, we fixed the flow to the 265 smallest water users, and only considered that the 623 largest water users were allowed to participate in the market. The largest water user is the City of Blenheim with a use of 1.3 Mm^3/day.

We did not have data on actual water use, and instead used the allocated water for each user as a starting point. We also did not have data for the value of water to various users, so we assumed identical bids for all users, based on proportional changes in allocations: a user would sell all water allocated at \$1/m^3, sell 83% of the water at 0.8 and sell 50% of the water at 0.6, buy 50% more water at \$0.4/m^3, and buy 75% more at \$0.2/m^3. The results are shown in Figure 3.

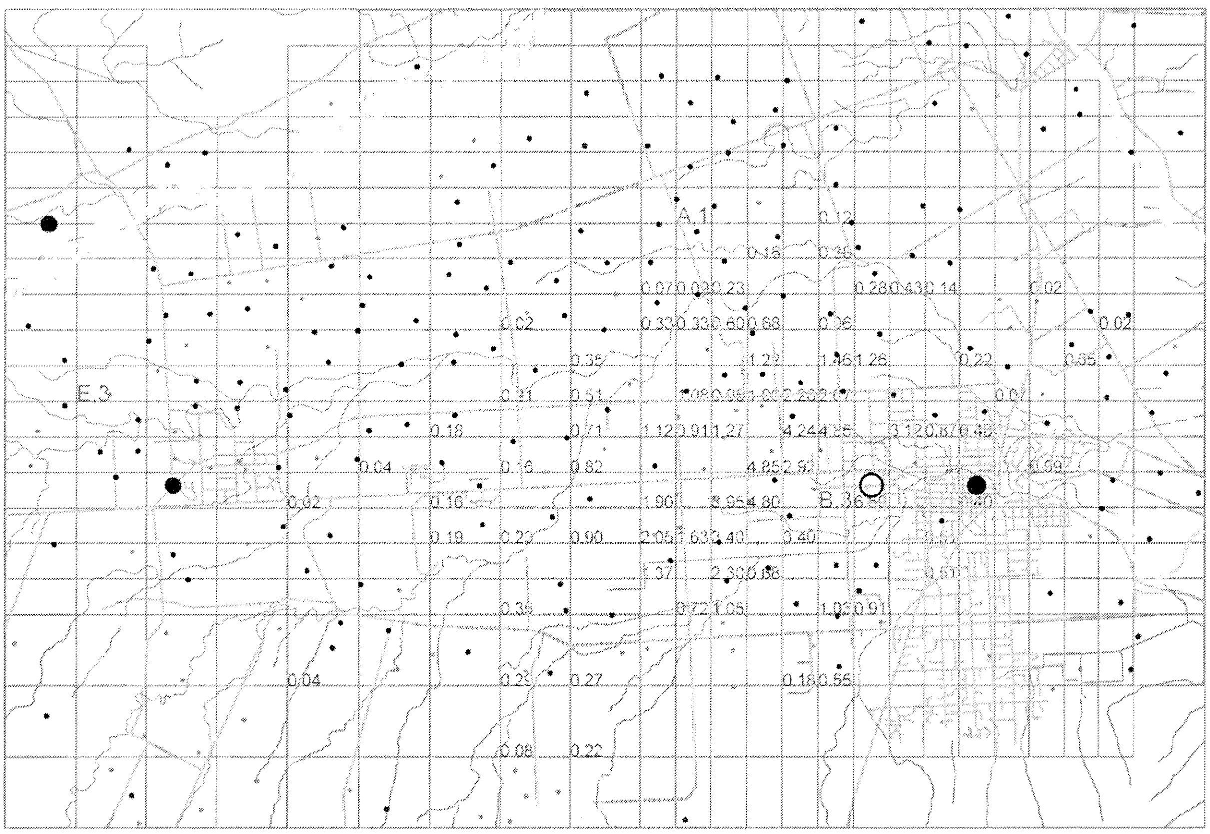

Figure 3. Results of the market software for Marlborough, NZ. The numbers shown in the grid cells are spot prices. In cells where no value is shown (including those cells not shown), prices are zero. The three large black dots are wells that are major buyers of water. The point B3 is an environmental control point. The circle near B3 is a Blenheim city well that is a major seller of water.

In Figure 3, water buyers are at those wells with prices less than 0.4, and water sellers are at those wells with prices greater than 0.6, and users sell all water where the price is greater than 1. The only binding environmental constraint is at point B3, and to meet this constraint, water prices are high near it, especially upstream (to the left) of B3.

Water cost decreases the further away users are from this critical point, until water has no cost where constraints are not close and even a 75% increase in water use would not lead to constraints being reached. These 'no-cost' results are partly an artifice of the assumed water price/demand curves.

These results show that if users near B3 were willing to sell, water use could be shifted elsewhere in the catchment without damaging the environment. The results also show a relatively high cost of water for the City of Blenheim. This in turn indicates how one could estimate the social cost associated with expansion of the city's water supply and ensure that an equivalent social benefit arises from that additional water use.

The results from the second example demonstrate that the system is technically viable, and the results also demonstrate the potential for valuable analysis even in cases where the system is not used in an active water market.

MODEL REFINEMENTS

Model sensitivity is one of three focal points for development work on the technology. We hope to examine the level of model detail necessary for the operation of a market. Existing models used by regional councils in water assessment may be overly detailed and could be simplified for use in water auctions. In addition, there is a desire to study the effects of water use by nearby wells, how models can describe short-term effects, and how auctions need to be constrained to limit unfairness or gaming between nearby users.

Another important refinement is the development of more realistic price/demand curves. Currently, we are not sure what suitable curves are, nor how prices might vary with variations in these curves. We hope to construct hypothetical scenarios with constrained hydrology to examine the effect of varying user demand curves on prices. For example, one would expect that the water resource would be more efficiently used by creating a mosaic of water users with inelastic water-pricing users far away from environmental constraints interspersed with elastic water users closer to environmental constraints. The long-term implications on land use based of a water market are worthy of further examination, but the hypothesis is that a spot market for ground water would lead to heterogeneity of land use in a given catchment.

It could also be that slight changes in specific hydrological parameters could lead to large differences in water price, which could lead to disputes over the appropriate constants used in the hydrological model. With more realistic price/demand curves, we intend to examine the issue of model sensitivity more closely. It is clear that water prices will also provide a signal to indicate where refinements in the hydrological model are most needed. Specifically, there is interest in studying the ability to model the effects of water use by nearby wells, and the effect of parameter uncertainty on trading decisions.

We aim to study the degree to which the response matrix is sufficiently accurate for market purposes. The time required to obtain the response matrix depends on the size and complexity of the hydrological model, and the number of wells. With the Marlborough example, we found that this can require several hours of computing time, even on a quad parallel processor.

Many key users, especially hydroelectric generators, are concerned that surface water and reservoirs be included in the market system. In fact, these features are easily managed through standard MODFLOW packages. Examples of optimisation for combined surface and ground water appear in the literature (e.g. Pulido et al 2002). The difficult part of implementing this system does not appear to be the addition of surface water, although we have not yet run realistic trials including surface water.

METHODS OF OPERATION

Various options for operation of the model are under investigation. The model itself is a general tool that can be adopted for multiple uses, including:

- a pure 'user-pays' regime where all water is purchased from a central organization and there is no right to water,
- a 'government-protection' regime where water users are compensated by government when water restrictions are needed to meet environmental objectives, and
- a 'user-trades' regime where water restrictions are not allowed to lead to payment to or from a central body, but instead lead to reductions in allocations before trades.

We have found that the market allocation of water is the same, independent of the initial allocation. Instead of changes in the final allocation, what changes is whether the auction manager has a net receipt or payment of money. Currently, we are examining the use of proportional reductions in water allocations to all users to ensure a 'user-trades' regime where the auction manager is revenue neutral. The use of proportional reductions means that only one variable needs to be adjusted to ensure that the water market remains revenue-neutral. Initial allocations can be set by other methods and we also would like to explore the use of 'classes' of water permits where certain users have complete priority over other users, as in the prior appropriation doctrine in parts of the U.S.

In addition, options are being explored for operation of the market by either an existing regulatory agency, a new quasi-governmental organization, or by a co-operative of water users who amalgamate their water use consents. The last option is intriguing because it points to the possibility of water users choosing to institute a water market even without the need for government to drive regulatory or legislative change. If the market can work in a revenue-neutral form for all water users, there would appear to be a win-win situation for water users and regulatory agencies to move towards a user-operated water market. The advantage for the regulatory agency would be the reduction in the number of water consents and the ability to provide clearer oversight by working with water professionals (i.e., the water market manager) rather than a number of less hydrologically trained water users.

There is also interest in exploring the potential for the use of 'futures' markets for water under this market model which merits investigation.

CONSULTATION

Changes in water allocation policy affect many individuals and interest groups. An integral part of our research effort is outreach and listening to public issues. It is encouraging that there has been interest in this research programme from regulatory bodies, irrigation groups, hydropower entities, and water protection interest groups.

In December of 2005, the New Zealand Hydrological Society sponsored a workshop in Auckland examining water trading. A wide variety of backgrounds were represented in the 34 participants. One interesting outcome from the workshop was the realisation that, in New Zealand, an open water market would require a decoupling of water quantity issues from other issues that are currently related to receipt and review of a water consent. Because the government in New Zealand owns the water and because the Resource Management Act recognises the potential for trading in s. 136, a water market is not as difficult to implement here as elsewhere. However, s. 136 appears to envision one-to-one transfer of water rather than a spot market as discussed here. To allow a spot market, regulatory authorities would need to change their Regional Plans modestly. Use of water purchased in a market could be considered a permitted activity, while the use of sold water would then need to be a prohibited activity. Our list of identified research needs includes further analysis of the RMA implications and effects on property rights.

Another important point raised at the workshop was the need for monitoring of compliance in any water trading system. The spot market discussed here would require that all users have water flow meters with data sent to the market manager. Still, there must be a simpler way to control water use than the public prosecution system now in use by local government for regulatory breaches.

The concerns regarding regulatory breaches and changes in Regional Plans apply when a market is operated by the current regulatory agency. It will be interesting to examine this further if water user co-operatives are considered further as the organisation of choice for the market manager.

We have found great value in workshop demonstrations of the software in action with a simplified catchment. The workshop allows individuals to see the impact of different bidding strategies on prices, and also see how prices can vary based on environmental constraints even with similar bids. With the increasing use of internet auction sites in New Zealand, we find that workshop participants very quickly can bid for water successfully.

We have found a challenge in having organisations take the step from expressing interest to becoming more involved in a trial implementation. Our perception is that the highly-charged political atmosphere related to water allocation makes it difficult for individual organisations to push for change to a more market-based approach without appearing to be lobbying for changes that will benefit them to the detriment of others. Curiously, currently competing interests will each recognise the need for markets privately, but not publicly. We find that interest is greater from larger organisations and from catchments where water quantity is more constrained. In addition, we are limited by the lack of financial resources to advance the research programme and will continue to consult with potential beneficiaries regarding financial contributions.

We are currently asking for letters of interest from organisations and will provide these interested organisations with newsletter updates on research and hope to build from that group of most-interested organisations towards a trial implementation. We welcome letters of interest and are willing to run workshops around the country or world as requested.

COSTS AND RISKS

As mentioned above, implementation of this system would require metering water use. A meter costs several thousand dollars, but councils are increasingly requiring metering, especially for larger users. Implementation would require the use of sophisticated hydrological models; however, the same models are required to manage the current water allocation system.

We see risks in operation of the system. Government could neglect rule enforcement (allowing cheating), or may neglect maintenance of the hydrology models. This system requires the rule of law, and would work best in a democratic society. Further, as demand for water increases, and as water moves to its highest value, we see the price of water increasing, though much more so without trading. Society may blame trading itself for the high price of water, rather than society's own demand for water.

BENEFITS OF IMPLEMENTATION

NZ's value for fresh water – local authority reticulation networks, irrigation, and hydroelectric generation – is estimated at $1.4 billion/year (StatisticsNZ 2004). Gains from optimisation in business (e.g. airlines and hydroelectric planning) are often 10% to 15%, so optimising the water resource could gain $140-220 million/year, through movement of water from lower to higher value use. Adoption of a water market holds the prospect of a measurable gain to national GDP.

In addition, a spot market developed in the way described would lead to more reliable attainment of environmental 'bottom lines', clear and correct price signals for water where before there were no prices signals, and fewer appeals and court cases associated with water consent applications. The hydrology simulation and optimisation guarantee the sustainability of any quantity. Thus, contention for consents is greatly reduced. Councils need no longer be the bearer of bad news by denying water permits. Instead, councils can focus on the environment.

In this system, users have no need to spend time seeking or advertising for water trades, because the central auction design matches buyers and sellers directly. Users do not need to make sure that the regional council will be satisfied, because the optimization enforces environmental flows automatically. Thus, the transaction costs are very low.

The system we are developing is not privatisation. In the system, the administrative permission to use water is traded. Our focus is mainly on larger water users. Our aim is to permanently solve NZ's key water allocation problems, while improving NZ's wealth and environment.

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